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Shale gas: Analysis of its role in the global energy market

Mehmet Melikoglu*

Department of Chemical Engineering, Gebze Institute of Technology, 41400 Gebze, Kocaeli, Turkey

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ABSTRACT

Shale gas revolution that took place in the United States at the beginning of the 21st century has still been shaping our global fossil fuel market. In 2012, the U.S. has surpassed Russia in natural gas production for the first time since 1982. At the same year, annual average U.S. Henry hub natural gas spot price decreased to $2.75 per million BTU, which was $8.69 per million BTU in 2005. In 2013, proved shale gas reserves of the world is estimated at nearly 2.7 trillion cubic metres (tcm) and unproved resources at staggering 203.9 tcm. As a result, there is a global rush to develop most of this resource as possible. However, shale gas is no miracle fuel. It has been suggested that its effects on the environment could be worse than conventional natural gas. Fugitive methane emissions, groundwater pollution, and increased seismicity are amongst the most important potential environmental side effects. There is also concern about the accuracy of resource potential estimations due to lack of data and specifically designed shale gas reservoir models. Nonetheless, the analysis in this study clearly showed that without developing global shale gas resources we have to consume 66% of our proved natural gas reserves to supply the demand till 2040. This would make most of the world natural gas importers, and rules of economy dictate that limited supply and increasing demand would skyrocket natural gas prices. Therefore, shale gas resource development is not an option but a must for the continuance of our global energy market and economy.

Contents

* Tel.: +90 262 605 21 21; fax: +90 262 605 21 05.
E-mail address: mmelikoglu@gyte.edu.tr

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1. Introduction

In 2011, the three types of fossil fuels: natural gas, oil, and coal provided 21.3%, 31.5%, and 28.8% of the global total primary energy supply (TPES), respectively; whereas, renewable energy sources provided merely 13.3% of the global TPES [1]. Thus, the share of fossil fuels in the global TPES was 81.6% or nearly 4.4 times the share of renewable energy sources. To be clear, the remaining 5.1% of the global TPES was supplied from nuclear power. Although, futurists in 1970s predicted that most of our energy need in 2000s would be supplied from renewable energy sources, we are living in world that is predominantly powered by fossil fuels [2].

Today, the TPES gap between renewables and fossil fuels is too wide to close, and there is no readily deployable energy generation technology that can provide the necessary replacement base load to stabilise the intermittency of renewable energy generation [3]. Also, the high monetary cost of renewable energy investments is a major problem [4,5]. As a result, it is evident that we will keep on using fossil fuels at these TPES ratios in the next couple of decades [6].

Out of the three types of fossil fuels, natural gas is becoming extremely important in the global energy market. Natural gas is a versatile fuel for electricity generation, heating, and transportation. Also, it has been identified as one of the principal options to reduce greenhouse gas emissions when shifting from other fossil fuels [7,8] over the entire life cycle. Life cycle assessment (LCA) is a well established method to understand the environmental impacts of energy conversion systems considering both renewable and non-renewable energy consumption during the whole life cycle [9,10]. From the LCA perspective, natural gas can be used to supply base load electricity with high technical flexibility if it can be supplied at lower costs [11]. As a result, there has been a continuous, steady growth of its consumption in domestic households, industry, and power plants around the globe over the last 40 years [12]. Timeline of global natural gas consumption is shown in Fig. 1 [13]. On the negative side, production of natural gas is geographically limited, as shown in Table 1 [13], and increased consumption in countries, which do not have indigenous reserves, worsen their trade deficit and cost billions of dollars each year. But, this might change soon as a result of the “shale gas revolution”, which took place in the United States in the early 21st century [14,15].

Today the U.S. natural gas price is around $4 per million British thermal units (BTUs), which is well below its ten year average of about $5.70 and prices of nearly $14 in Britain and $17 in Asia [16]. Detailed information about the U.S. Henry hub natural gas spot price is reported in Table 2 [17]. In addition, the U.S. surpassed Russia in natural gas production last year, pulling ahead for the first time since 1982 [18]. As a result of this dramatic change in the U.S. natural gas supply, other countries who import natural gas but also proved to have large shale gas deposits, like China, the United Kingdom, and Turkey are now keen to develop their resources [19–21]. It is anticipated that this trend will spread to other countries and shale gas investments will increase at an exponential rate in the second half of this decade.

However, shale gas development also has its cons. The opponents are highly concerned about its potential environmental impacts on our climate and energy security. Linguist and author, Noam Chomsky is highly concerned about the environmental impacts of shale gas development. Quoting his opinion about this subject: “When you turn to energy production, in market exchanges each participant is asking what can I gain from it? You don't ask what are the costs to others. In this case the cost to others is the destruction of the environment. So the externalities are not trivial” [22]. Also, Claude Turmes who is a member of the European Parliament for Luxembourg's Green Party and green energy spokesperson considers that shale gas as a dangerous Trojan horse for Europe's energy policy [23].

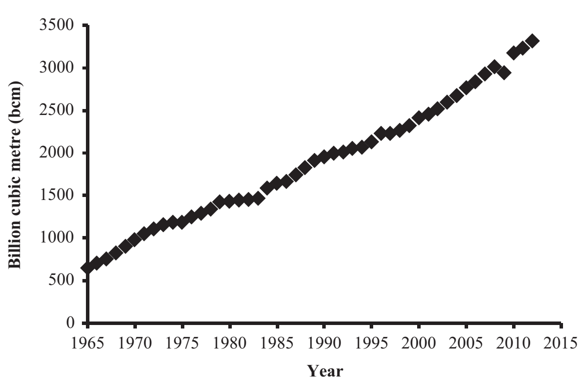


Fig. 1. Global natural gas consumption, in billion cubic metres (bcm) [13].

Table 1
Global natural gas production in 2012 by region, in billion cubic metres (bcm) [13].

Region	Production (bcm)	Share of total (%)
Total Europe & Eurasia	1035.4	30.7
Total North America	896.4	26.8
Total Middle East	548.4	16.3
Total Asia Pacific	490.2	14.5
Total Africa	216.2	6.4
Total South & Central America	177.3	5.3
World total	3363.9	100.0

Table 2
The U.S. Henry Hub Natural Gas Spot Price (dollars per million Btu) [17].

Year	Price (dollars per million Btu)
1997	2.49
1998	2.09
1999	2.27
2000	4.31
2001	3.96
2002	3.38
2003	5.47
2004	5.89
2005	8.69
2006	6.73
2007	6.97
2008	8.86
2009	3.94
2010	4.37
2011	4.00
2012	2.75

As a result of this debate, many people from the academic and engineering community want to know more about shale gas to make a sound judgement about its potential role in our global energy mix of tomorrow. Consequently, this paper is intended to prepare that crucial review starting with the technical information about the formation and recovery of shale gas. Followed by explaining the environmental impacts associated with its production, and finally analysing the global potential in comparison with natural gas reserves and consumption projections.

2. Shale gas formation and recovery

2.1. Formation

Shale "play" is a specific geographical area, which is targeted for exploration by the oil and gas industry due to the belief that there is an economic quantity of petroleum and natural gas to be extracted there [24]. Specifically, gas shales are organically rich, fine grained sedimentary rocks containing important quantities of natural gas [25]. Shales produce methane (primary component of natural gas) through biogenic (predominant), thermogenic, or combined biogenic-thermogenic reactions [26]. Biogenic gas is generated from anaerobic bacteria, which produce methane during early diagenesis; whereas, thermogenic gas is generated from thermal cracking of kerogen at extremely high temperatures (between 150 °C and 250 °C) and pressures [27,28]. Due to the geology and lower permeability of the source rocks the produced natural gas is trapped in shale reservoirs [29,30].

The shale formations typically function as both the reservoir and the source rocks for the natural gas [31]. Thus a shale gas reservoir is characterised as a self-contained source-reservoir system [32]. Shale reservoirs are extremely tight, with pores in the range of nanometres and permeabilities in the range of nanodarcys; and consequently, gas sorption and diffusion processes are rather complex [33]. The total shale gas content in the reservoirs is composed of three portions: (i) the adsorbed gas content, (ii) the free gas content, and (iii) the dissolved gas content [29,34,35]. Since the dissolved gas in shale is rare (negligible), the total shale gas content can be approximately equal to the sum of the adsorbed gas content and the free gas content and determination of the adsorbed gas content (AGC) is the main issue encountered in shale gas resource evaluation for economic purposes [34]. When a shale play with high natural gas potential is identified, the trapped natural gas is recovered via a series of advanced processes.

2.2. Recovery

Shale gas is classified as an unconventional source of natural gas [36]. Thus its recovery is different than the conventional methods [29,37]. The main differences between shale gas development and conventional natural gas extraction are horizontal drilling and high-volume hydraulic fracturing (fracking) [38,39]. After building the necessary site infrastructure production wells are drilled vertically to a depth between 2000 and 3000 m depending on the geological formation of the shale and followed by horizontal or directional sections [29]. While, the integrity of the well is maintained by a combination of the casing and cementing [38]. When the well is drilled the hydraulic fracture is formed by pumping the higher pressure fracturing fluid into the wellbore to shale rock [29]. Fractures have an important role in the shale gas reservoir formation because they can enlarge aggregation spaces and transport channels, and increase specific surface are of the shale; and therefore, the natural fracture system must be fully integrated with the fracture system produced via hydraulic fracturing of these reservoirs [40].

Water and sand proppant generally makes more than 98% of the fracture fluid, and the rest consisting of various chemical additives, which improve the effectiveness of the fracturing [38,41]. The fractures generally extend a few hundred metres into the shale and these newly created fractures are propped open by the sand, and when the fracturing ends the well is depressurised, which creates a pressure gradient so that gas flows out of the shale into the well [42]. In this way the gas is recovered from the shale. However, as long as the well continues to produce shale gas fracturing fluid containing saline water with dissolved minerals from the shale formation returns to the surface and this creates environmental concern because these returns are classified as wastewater [42]. Although, shale gas extraction seems to be environmentally benign consideration of risks of future damages from associated production activities might be advantageous [43].

3. Environmental problems associated with shale gas production and fracking

Environmental impacts associated with shale gas production and fracking can grouped under three main categories: (i) ground water contamination and wastewater generation, (ii) greenhouse gas and fugitive methane emissions, and (iii) increased seismic activity [44]. Details of which are explained in the subsections below.

3.1. Groundwater contamination and wastewater generation

Groundwater contamination due to failures associated with well drilling and hydraulic fracturing is a major public concern, especially in densely populated areas where ground water is essential for drinking, agriculture and industrial use [45,46]. It is estimated that groundwater contamination is higher when producing natural gas from shale and tight sandstones, which require horizontally completed wells and massive hydraulic fracturing that injects large volumes of high-pressured water with added proppant (up to 50,000 m^3/well) and toxic organic and inorganic chemicals [47]. It is difficult or nearly impossible to decontaminate groundwater; therefore, it is essential to appraise the shale gas development condition, which could lead to contamination [46].

Table 3
Common wastewater/fluid streams related to shale gas well development [48].

Type	Properties
Brine	Brine is the subsequent wastewater fluids recovered from the well for the remainder of its operating life, which is typically in relatively small volumes, once the well has been put into production.
Drilling muds	These are dense, clay-rich slurries continuously circulated on site to lubricate and cool the drill bit during the well drilling phase and lift drilling cuttings to the surface. Drilling muds must be either treated or reused and disposed when drilling is complete. Their overall volume is comparatively small compared to other waste fluids.
Flowback wastewater	Flowback wastewater is recovered from the well after hydraulic fracturing but before putting the well online for production. Flowback is a combination of chemical constituents originating from the shale and hydraulic fracturing fluid returning to the surface after well depressurisation. Flowback is the largest wastewater stream by volume for shale gas development. According to the U.S. Environmental Protection Agency (EPA) in the first 30 days of fracturing up to nearly 3.8 million litres of flowback water can be produced from a single shale gas well and this wastewater generally contains an elevated salt content, organics, metals and NORM (naturally occurring radioactive material) together with the conventional pollutants [49].

Another water related problem is wastewater generation during fracking. This wastewater/waste fluid is generally grouped under drilling muds, flowback wastewater and brine. Details of which are explained in Table 3 [48,49]. Also, there is public concern with the fate of the water, which is retained in wells. Water imbibition in relevant shales must be well studied in order to improve the understanding of the physical mechanisms, which control fluid transport and subsequent gas recovery [50]. Overall, water is a key resource [51] and strict environmental regulations are required to guarantee that the impacts of shale gas production on water sources is minimised.

3.2. Greenhouse gas and fugitive methane emissions

Greenhouse gas emissions from shale gas development and consumption can be grouped under two categories: (i) carbon dioxide produced when shale gas is burned and the methane that leaks out, and (ii) emission from the energy employed during the extraction and transportation of the shale gas produced [49]. Fugitive methane is the gas, which is leaked during the complete fuel cycle (from extraction to burning) and majority of the fugitive methane emissions are process related, and 58% of it come during field production [44].

In 2011, Howarth and colleagues evaluated the methane emissions from natural gas obtained by high-volume fracking from shale formations and estimated the total fugitive methane emissions (expressed as the percentage of methane produced over the lifecycle of a well) associated with development from shale formations, between 3.6% and 7.9%, were substantially higher than for conventional gas well, between 1.7% and 6.0% [52]. They also concluded that methane emissions contribute substantially to the greenhouse gas footprint of shale gas, whose footprint is greater than that for conventional gas or oil when viewed on any time frame, but especially so over 20 years [52].

On the positive side, Wang and co-workers suggested that the greenhouse gas emissions from the shale gas operations could be reduced by reducing CH_4 emissions and incorporating carbon capture and storage to store CO_2 in depleted shale gas reservoirs, which have the potential to store more CO_2 than the equivalent CO_2 emitted [53]. Overall, detailed scientific and engineering work is required to quantitatively measure the greenhouse gas emissions from shale gas development over its lifecycle, which include drilling, fracking, recovery, processing, transportation, and final consumption.

3.3. Increased seismic activity

It is known that hydraulic fracturing triggers micro-seismic activities; however, recently this phenomenon gained increased attention due to occurrence of low-magnitude earthquakes, near injection disposal wells where no previous earthquake activity had been reported [54]. Such events happened at Dallas–Fort Worth, TX; Cleburne, TX; Timpson, TX; and Youngstown, OH in the United States, where the injected fluids were generated by shale gas development projects where wells are hydraulically fractured and the flowback fluids were disposed by injecting them elsewhere in designated Class II disposal wells.

These low-magnitude earthquakes could occur due to the presence of faults and the potential for reactivation of these faults. Recently, Rutqvist and co-workers carried out numerical simulations to assess the potential for injection-induced fault reactivation and prominent seismic activity associated with shale gas hydraulic fracturing, and their modelling simulations showed that when faults are present the magnitude of micro-seismic events is somewhat larger than the ones originating from regular hydraulic fracturing due to the larger surface area that is available for rupture [55].

In a recent study Davies and his colleagues reported that, due to increase in the fluid pressure near a fault zone hydraulic fracturing operations can trigger seismicity and based upon their research they proposed that this could occur by three mechanisms: (i) entry of displaced pore fluid or fracturing fluid into the fault, (ii) "direct connection with the hydraulic fractures and a fluid pressure pulse could be transmitted to the fault", and (iii) "due to poroelastic properties of rock, deformation or 'inflation' due to hydraulic fracturing could increase fluid pressure in the fault or in fractures connected to the fault" [56].

Nonetheless, there is an increasing public concern and fear about earthquakes due to shale gas development/fracking near densely populated areas [57], And keeping in mind that population centres overlie shale deposits in countries like China, England, India, Poland, Turkey and the United States [58] increased attention should be given on continuous monitoring of induced seismicity during the entire operation of shale gas development.

4. Global shale gas potential and production projections

In 2013, the U.S. Energy Information Agency (EIA) estimated the proved shale gas reserves of the world is nearly 2.7 trillion cubic metres (tcm), and the unproved resources are greater than 200 tcm [59]. Details of technically recoverable shale and natural gas resources and reserves of the world are given in Table 4. As can be seen from this table, inclusion of shale gas increased the total natural gas resources 47% and solely makes up 32% of the global natural gas resources. As a result, there is a global rush to develop most of this potential. The top 10 countries with technically recoverable shale gas resource potential are reported in Table 5.

From energy systems engineering perspective, the shale gas resource potentials alone do not show the overall picture. Because, shale gas is an unconventional form of natural gas and without proved natural gas reserves and consumption projections one cannot make a sound judgement about the role of shale gas in the global energy mix of tomorrow. As a result, proved natural gas reserves and consumption projections till 2040 for the top 10 countries with technically recoverable shale gas resources in the world are reported in Tables 6 and 7 based on the data by the U.S. Department of Energy, Energy Information Agency (EIA) [60–62]. For clearance, the total natural gas consumption till 2040 for the top 10 countries with technically recoverable shale gas resources in the world are calculated by carrying out a regression analysis using the average annual % change in natural gas consumption between 2010 and 2040 data, which are given in column 4 of Table 7, and natural gas consumption statistics at the base year 2010, which are given in column 2 of Table 7. The results are reported in column 6 of Table 7. Also, using these data the following ratios: (total natural gas consumption between 2010

Table 4
Technically recoverable shale and natural gas resources and reserves of the world, 2013 estimation, adapted from [59].

	Wet natural gas (trillion cubic metre)
Shale gas proved reserves	2.7
Shale gas unproved resources	203.9
Other proved natural gas reserves	190.9
Other unproved natural gas resources	250.4
Total	647.9
Increase in total resources due to inclusion of shale gas	47%
Shale as a per cent of total	32%

and 2040)/(proved natural gas reserves) and (total natural gas consumption between 2010 and 2040)/(proved natural gas reserves + technically recoverable shale gas resources) are calculated for the top 10 countries with technically recoverable shale gas resources in the world and the results are reported in Table 8. The comparisons drawn based on these data are reported in the next section.

Table 5
Technically recoverable shale gas resources around the globe, 2013 estimation, adapted from [59] (note: may not sum to total because of rounding).

Country	Shale gas resource (trillion cubic metre)
China	31.6
Argentina	22.7
Algeria	20.0
U.S.	18.8
Canada	16.2
Mexico	15.4
Australia	12.4
South Africa	11.0
Russia	8.1
Brazil	6.9
Other countries	43.5
World total	206.7

Table 6
Proved natural gas reserves of the top 10 countries with technically recoverable shale gas resources in the world, in 2012 [60].

Country	Natural gas reserves (trillion cubic metre)
China	3.0
Argentina	0.4
Algeria	4.5
U.S.	9.5
Canada	1.7
Mexico	0.5
Australia	0.8
South Africa	0.016
Russia	47.6
Brazil	0.4
World total	193.8

5. The top 10 countries with technically recoverable shale gas resources in the world

According to the data given in Table 5, China has the largest technically recoverable shale gas resource around the globe, estimated at staggering 31.6 trillion cubic metres. Argentina and Algeria follow China with the world's second and third largest shale gas resource potentials. The United States, world's premier economy and second largest energy consumer has the fourth largest shale gas resource potential in the world, estimated at 18.8 tcm. Canada, Mexico and South Africa follow the United States. Russia, which has vast fossil fuel sources, also has the 9th largest shale gas resource potential around the globe, estimated at 8.1 tcm. Finally, Brazil has 6.9 tcm of shale gas resource potential. In total, the top 10 countries have an estimated 163.1 tcm of shale gas resource potential, whereas the rest of the world has only 43.5 tcm. In other words, the top 10 countries have 79% of the world's shale gas resource potential. A comparative assessment across the top 10 countries with technically recoverable shale gas resources in the world is given in the subsections below.

5.1. The United States

The United States is worlds' premier natural gas producer and together with Canada make up >25% of global production [63]. In 2010, shale gas accounted for 23% of the U.S. total gas production, which is projected to increase 49% of the total by 2035 [63]. Today, the production cost of shale gas in the U.S. is cheaper than

Table 8
Ratios of (total natural gas consumption between 2010 and 2040)/(natural gas reserves) and (total natural gas consumption between 2010 and 2040)/(shale resources + natural gas reserves) in the top 10 countries with technically recoverable shale gas resources in the world.

Country	$\frac{\left(\sum_{2010}^{2040}(\text{Natural gas consumption})\right)}{\sum(\text{Natural gas reserves})}$	$\frac{\left(\sum_{2010}^{2040}(\text{Natural gas consumption})\right)}{\sum(\text{Natural gas reserves} + \text{shale gas resources})}$
China	2.61	0.23
Argentina	4.84	0.08
Algeria	0.33	0.06
U.S.	2.50	0.83
Canada	1.94	0.19
Mexico	7.33	0.23
Australia	1.72	0.10
South Africa	12.75	0.02
Russia	0.31	0.27
Brazil	3.55	0.20
World Total	0.66	0.32

Table 7
Total natural gas consumption (trillion cubic metre, tcm) in the top 10 countries with technically recoverable shale gas resources in the world, between 2010 and 2040 [61,62].

Country	Total natural gas consumption in 2010 (tcm)	Ref.	Average annual % change in natural gas consumption between 2010 and 2040	Ref.	Total natural gas consumption till 2040 (tcm)	Ref.
China	0.107	[61]	5.3	[62]	7.9	Current study
Argentina	0.043		2.0		1.8	
Algeria	0.029		3.1		1.5	
U.S.	0.682		0.7		23.6	
Canada	0.082		1.7		3.3	
Mexico	0.065		3.6		3.6	
Australia	0.033		1.7		1.4	
South Africa	0.004		3.1		0.2	
Russia	0.424		0.9		15.0	
Brazil	0.025		3.9		1.5	
World total	3.209		1.7		128.7	

natural gas around most of the world [64], which is believed to be the trigger for the increased global attention on shale. Technically recoverable shale gas resource potential of the United States is estimated at 18.8 tcm. This is almost twice the amount of the proved natural gas reserves of the country. In this study, it is estimated that the total natural gas consumption in the United States between 2010 and 2040 would be 23.6 tcm. This huge consumption is 2.50 times the proved natural gas reserves and 83% of the shale resources plus the proved natural gas reserves of the United States. Consequently, shale gas development is a must, not an option for the U.S. to satisfy the country's massive natural gas consumption in the next 30 years. However, the results also show that neither natural nor shale gas would be a viable, sustainable solution to the U.S. massive energy demand. Considering also the country's limited petroleum and coal reserves it is evident that the U.S. must pass to a renewable energy based economy in the second half of this century. Thus, shale gas could provide a smoother transition over the next 30 years.

5.2. China

China has the world's largest shale gas resource potential, the biggest energy market and the government is eager to expand its gas production [65]. The country's shale gas resource is estimated at 31.6 tcm in 2013. This is almost 10 times the proved natural gas reserves of the country. As a result, global energy firms Shell, Exxon Mobil, Chevron, Eni and Total are actively trying to extract most of this valuable resource [66]. Among them Royal Dutch Shell p.l.c is the first to land a production sharing contract, who is working with Chinese oil giant Sinopec Corp for joint evaluation of shale resources in Xiang E Xi (XEX) block, at the junction of central Hunan, Hubei and Jiangxi provinces in east central China; and also in Sichuan conducting evaluation drilling of the Fushun-Yongchuan block in partnership with Chinese primary oil and gas producer PetroChina, and expected to start commercial production after 2014 [66]. Sinopec and PetroChina estimated their shale output in 2015 at around 2 billion cubic metres (bcm) each [20].

There are also serious problems in front of shale gas production in China. The shale gas resources are found mostly in the arid west and southwest at deeper locations like Cambrian, Ordovician and Silurian strata of China [67]. And specifically, for shale gas production in Southern China the following problems lay in front of international and local investors: the effects of nanopore formation on shale gas production are unclear; the prediction methods for shale gas production have not yet been established; the horizontal section might collapse in the process of drilling, the drilling cycle is too long, and finally the stimulation effect is not ideal with low single well production [67]. In addition, China does not have the required infrastructure to process the shale gas at larger volumes in a shorter period. In 2013, the U.S. Secretary of Energy, Ernest Moniz, stated that the U.S. have a favourable geology for producing shale gas, have the most mature natural gas infrastructure in terms of pipelines, market structures, trading hubs, futures contracts, regulation of production etc.; and if China wants to develop its resources “at a large scale in rapid fashion” they must tackle these issues [68].

In this study, it is estimated that the total natural gas consumption in China between 2010 and 2040 would be 7.9 tcm. This huge consumption is 2.61 times the proved natural gas reserves and 23% of the shale resources plus the proved natural gas reserves of the country. Consequently, if the shale gas resources of China would be proven to be true, world's largest energy importer may not need to import natural gas in the second quarter of the 21st century.

5.3. Argentina

In 2010, total natural gas consumption in Argentina was merely, 0.043 tcm. This mediocre consumption is related to the countries small natural gas reserves recorded at 0.4 tcm. However, things are about the change in Argentina. Because, Vaca Muerta, which is located Neuquen province in south-western Argentina, is considered as the world's second largest shale gas formation [69]. The total shale gas resource of the country is estimated at 22.7 tcm or 60 times the proved natural gas reserves. As a result, there is an increasing attention from the international energy firms to develop as much of this resource available. Recently, Shell Argentina announced that the company will increase its shale capital expenditures to nearly $500 million in 2014 from $170 million at year end [70].

In this study, it is estimated that the total natural gas consumption in Argentina between 2010 and 2040 would be 2.0 tcm. If the huge shale resources of the country would not be extracted this amount of consumption would be equal to 4.84 times of the proved natural gas reserves of Argentina. Thus the country would have to import all of its natural gas demand. However, with the inclusion of shale gas the country could be a main natural gas exporter. This is quite important in terms of local and international energy dynamics.

5.4. Algeria

Algeria is already a major exporter of oil and natural gas and the country could become an even bigger exporter in the coming years as it develops its huge shale gas reserves trapped in shale rock more than 1000 m below the surface [71]. Algeria's proved total natural gas reserve is estimated at 4.5 tcm and shale gas resources at 20.0 tcm. In this study, it is estimated that the total natural gas consumption in Algeria between 2010 and 2040 would be 1.5 tcm. Also, it was estimated that Algeria's recoverable shale gas reserves are enough to supply the entire European Union for a decade and valued at about $2.6 trillion at November 2012 U.K. prices; and shale gas could double Algeria's marketed gas production to 160 bcm per annum during the next two decades, and the country could export 110 bcm by 2030 [72]. Thus the country would be a key player in the shale gas market and considering its geographical location and existing natural gas infrastructure it may supply cheap shale gas to the European Union, which the continent desperately needs in the 2020s.

5.5. Canada

Total proved natural gas reserve of Canada is estimated at 1.7 tcm. Canada also has large shale gas deposits in British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick and Nova Scotia [73]. The total shale gas resources of the country are estimated at 16.2 tcm or 9.4 times the proved natural gas reserves. In 2010, natural gas consumption in the country was 0.082 tcm and it is estimated that the total natural gas consumption in the country between 2010 and 2040 would be 3.3 tcm. This amount of natural gas consumption would be equal to nearly two times the proved natural gas reserves of the country. However, with the inclusion of shale gas this could decrease down to 0.20. Of course, this is conditional to the fertility of the shale gas resources. Different than other countries with large shale gas deposits, there is a large public unrest about the development of this resource. At the end of 2013, there were a serious of “anti-shale gas” demonstrations [74] and this public unrest is the main problem in front of shale gas development in Canada so far.

5.6. Mexico

Natural gas consumption in Mexico in 2010 was at modest 0.065 tcm and total proved natural gas reserve of the country is estimated at 0.5 tcm. As a result, natural gas consumption in the

country has not increased to significant levels. However, it is found that Mexico has the world's 6th largest recoverable shale-gas reserves, estimated at 15.4 trillion cubic metres or staggering 31.5 times the proven natural gas reserves. In this study, it is estimated that natural gas consumption in the country between 2010 and 2040 would be 3.6 tcm, which is 7.33 times the proved natural gas reserves. In order to supply this increasing demand from indigenous sources Mexico should start developing its vast shale gas resources. Yet only minimal investment in shale gas has taken place in Mexico [75].

5.7. Australia

Australia has large shale gas deposits and Cooper Basin is considered as the only region outside of the U.S., which is commercially producing shale gas [76]. Total shale gas resource of the country is estimated at 12.4 tcm, which is 15.7 times the proved natural gas reserves, estimated at 0.8 tcm. In 2010, 0.033 tcm of natural gas was consumed in Australia, and it is estimated that, between 2010 and 2040, 1.4 tcm of natural gas would be consumed. If the shale resources of the country can be developed Australia would also be a major exporter of natural gas.

5.8. South Africa

Shale gas resources of South Africa is estimated at 11.0 tcm, which is staggering 690 times the proven natural gas reserves of the country, estimated at 0.016 tcm. That makes South Africa the most interesting country for shale gas development. In 2010, natural gas consumption in South Africa was 0.004 tcm, and it is estimated that till 2040 totally 0.020 tcm of natural gas will be consumed. Thus the vast shale gas reserves of the country are waiting to be developed by the government and international energy companies. South Africa published proposed regulations for fracking on 15 October 2013 and plans to issue licences for shale gas development in the first quarter of 2014 to develop huge shale gas reserves available in the semi-arid Karoo region [77,78].

5.9. Russia

Fossil energy giant Russia also has substantial shale gas reserves. Estimated at 8.1 tcm, however this huge amount is only 17% of the country's vast proved natural gas reserves, estimated at 47.6 tcm. As a result, chief executive of Russian energy giant Gazprom, Alexander Medvedev said that Russia shouldn't care too much about it, at least this century [79]. Instead, the country is currently focusing on developing its vast conventional natural gas reserves.

5.10. Brazil

Although, more than 80% of Brazil's electricity is generated from hydropower, a dry spell that pushed dam levels to the lowest since 2000 has forced the government to order the use of natural gas power plants without having enough domestic gas to feed them [80]. In 2010, natural gas consumption in the country was 0.025 tcm. Brazil has little proved natural gas reserves estimated at 0.4 tcm. Consequently, Brazil is seeking to cut dependency on liquefied natural gas imports by preparing for its first-ever auction of shale-gas acreage to develop the country's vast reserves [80]. Shale gas resources of the country is estimated at 6.9 tcm and if successfully develop could change Brazil from a natural gas importer to an exporter.

5.11. The European Union

Up till this point, production projections in the top 10 countries with technically recoverable shale gas resource potential are investigated. However, when the subject is shale (natural) gas we should also understand the position of the European Union, a major importer of natural gas. Today Russian Federation is the country of origin for 31.9% of natural gas imports (excluding Intra-EU trade), Norway supplies 29.4%, Algeria 13.8%, Qatar 8.7% and Nigeria 3.4%; natural gas dependency in the EU-27 is 65.6% in 2012, slightly decreasing from 67.3% in 2011; the Netherlands and Denmark are the only net exporter; and in 15 EU member states, the energy dependency is higher than 90% [81]. As a result, shale gas production could help the EU to decrease its increasing natural gas import bill and dependency to other countries.

Unfortunately, as of today, there is no commercial shale gas production in the EU, and there is uncertainty about future production [44]. Because, there is no unified EU policy on the utilisation of shale gas resources [82]. The EU also considers buying cheap shale gas in the form of liquefied natural gas (LNG) from the United States. However, according to Peter Voser, CEO of Royal Dutch Shell, the U.S. shale gas exports in the form LNG would not significantly decrease the natural gas prices around the world because of the additional costs of liquefying; transporting; and finally depressurising the gas would mean its final cost would be comparable to existing market prices [83]. As a result, the EU would not be a key player in the global shale gas market for the foreseeable future.

5.12. A comparative assessment across the top 10 countries with technically recoverable shale gas resources in the world

If we consider shale gas resource potential as the only parameter, China has the world's largest potential and should be the most opportune country for shale gas development. However, shale gas must be analysed together with natural gas as emphasised above. The detailed analysis carried out in this study showed that if the shale gas resources can be converted to reserves at 100% level, South Africa would benefit most from this new fossil fuel. As can be seen from Table 8, the country's natural gas consumption till 2040 is 12.75 times the country's proven natural gas reserves. However, in the like likelihood of a shale gas revolution the country would consume only 2% of its shale gas resources and natural gas reserves till 2040. Indeed, this would change the country from being an importer to a prominent energy exporter. Shale gas would also have a significant change in Argentina's energy balance. The country's natural gas consumption till 2040 would be equal to 4.84 times the country's proven natural gas reserves. However, by successfully developing shale gas the country would consume 8% of its shale gas resources and natural gas reserves till 2040. Similarly, for Mexico this ratio would decrease to 23% from staggering 733%. Shale gas revolution would benefit all the top 10 countries with technically recoverable shale gas resources. The natural gas consumption to reserve ratios of these countries except Algeria and Russia would decrease below 1.0 when shale gas resources are successfully developed (Note: for Algeria and Russia this ratio is already <1.0 due to these countries vast natural gas reserves). And, it is highly likely that some of these top 10 countries, which have lower indigenous consumption, would become major shale/natural gas exporters in the near future.

6. Conclusion

Detailed analysis of the literature showed that shale gas development is now a mature industry in the United States. But it is still in its nascent stages around the rest of the world. Asset

valuation based on the success in the U.S. is the primary motive behind the global rush to develop as much shale gas as possible. However, the future of shale gas is subject to multiple economic, physical, political and technical uncertainties [84,85]. From scientific perspective exporting the United States shale gas experience to another country simply does not guarantee the same success. Because, shale gas reservoirs vary in properties such as origin, permeability, and porosity; thus differences in properties of the shale gas must be expected [86]. Also, shales in other countries might not be as fertile as in the U.S. and the infrastructure and engineering facilities might not be as adequate [87]. Also, there are still problems about the accuracy of shale gas resource potential [88,89]. For example, in 2011 EIA estimated the global shale gas potential at 187.5 tcm, but updated this figure to 206.7 tcm in 2013 [90]. This means a 10% inaccuracy in resource capacity estimation.

Nonetheless, it is expected that shale gas development will continue at an accelerated rate around the globe in the next years. As a result, it will have an increased share in our global energy mix, and probably decrease the global natural gas prices to some extent. However, increased shale gas production would also increase greenhouse gas emissions at global level. Besides the direct impacts on climate, there would be major economic constraints when the global carbon tax will be effective. Also, there is the possibility to deal with the groundwater pollution and increased seismic activities if they are also proved to be related to shale gas development. Consequently, the real impacts of shale gas development will be revealed in the near future.

Finally, the whole enthusiasm with shale gas development lay with the estimated resource potentials. As can be seen from Table 4, only 1% of the global shale gas resources are actually proved reserves, which means there is a significant risk involved in potential estimations. If all these resources can be successfully converted to proved reserves that's all good. But if we fail, our global natural gas consumption till 2040 would consume 66% of our proved natural gas reserves as shown in Table 8. In this worst case scenario, most of the countries in the world would become natural gas importers and market dynamics suggest that natural gas prices would skyrocket. As a result, shale gas is not an option but a must for the furtherance of our global energy market and economy. And we need to sustainably develop most of this resource in the next 30 years by considering and preventing most of its associated environmental impacts.

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